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Spatial and Temporal Analysis of Severe Dust Storm in Iraq in May 2022

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Abstract

Dust storms are a common ecological occurrence in many world‘s countries, mainly in dry and semi-dry parts. Dust storms tremendously influence human health, the environment, the climate, and numerous social aspects. In this paper, spatial and temporal analysis, metrological triggers, and trajectory, dust exporting areas of a severe dust storm that occurred in Iraq on May 16, 2022, were investigated. The dust storm's backward trajectory was determined using HYSPLIT model, which is then compared with MODIS and Meteosat satellite images. The weather is then analyzed using the NCEP/NCAR Reanalysis model, and the approximate area of these sources was determined using Landsat 8 satellite image classification method. The results revealed that the HYSPLIT model trajectory of the dust storm agreed with MODIS and Meteosat satellite visuals. The primary dust storm sources and their areas are identified. The first source is from the shared border region between Syria (Rif-Dimasshq) and Jordan (north of Al-Ruwaished), with an area of about 775 km^2. The second is from the northwestern regions of Iraq, specifically north of Anbar and south of Nineveh, with an area of about 905 km^2.

Keywords: Dust Storm, MODIS, HYSPLIT, Landsat, Iraq.

التحليل المكاني والزماني للعاصفة الغبارية الشديدة في العراق في آيار 2022

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الخلاصة

تعتبر العواصف الترابية ظاهرة بيئية شائعة في العديد من بلدان العالم ، ولا سيما في المناطق الجافة وشبه الجافة، لما لها من تأثير كبيرعلى صحة الإنسان والبيئة والمناخ والعديد من المتغيرات الاجتماعية والاقتصادية. في هذا العمل تم التحليل المكاني والزماني ، والتحقق من المُسببات المترولوجية ، المسارالخلفي ومناطق تصدير الغبار للعاصفة الغبارية الشديدة التي حدثت في العراق في 16 مايو 2022 ، تم تحديد المسار الخلفي للعاصفة الترابية باستخدام نموذج HYSPLIT، والذي تمت مقارنته بعد ذلك مع صور الأقمار الصناعية MODIS وMeteosat. ومن ثم يتم تحليل الطقس باستخدام نموذج إعادة التحليل NCEP/NCAR، ويتم

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التعرف على مصادر العاصفة الترابية باستخدام القمر الصناعي LANDSAT 8 وطريقة تصنيف الصور.
أشارت النتائج إلى أن مسار نموذج HYSPLIT للعاصفة الغبارية يتوافق مع صور الأقمار الصناعية Meteosat, MODIS.
تم تحديد مصادر العاصفة الغبارية الرئيسية. المصدر الأول من المنطقة الحدودية المشتركة بين كل من سوريا (ريف دمشق) والأردن (شمال الرويشد) بمساحة حوالي (775) كيلومتر مربع. والثاني من مناطق شمال غرب العراق وتحديداً شمال الأنبار وجنوب نينوى بمساحة حوالي (905) كيلومتر مربع.

1.Introduction

Dust storms are natural calamities that millions worldwide suffer yearly [1]. The Middle East and Central Asia are the second-largest dust sources, contributing around 30% to worldwide dust loading [2], [3]. The tremendous impact that dust in the atmosphere has on climate and air quality is one of the most significant environmental effects [4], [5]. Iraq and other nations in semiarid and arid regions of have been troubled by dust storms [6]. Dust storms have become far more prevalent in Iraq over the past twenty years because of erosion and water shortages, especially in spring and summer [7]. Iraq is a significant source of airborne dust in the Middle East, with large expanses of sand desert [8], [9]; other significant dust storms affecting different parts of Iraq include the deserts of Syria, Jordan, Arabia, and North Africa [7]. Severe dust generation results from climatic conditions, wind patterns, surface characteristics, terrain, and human activity [10]. Strong, sustained, regular, and seasonal winds induce sandstorms lasting hours to days that cause dust to spread over the country [11]. Dust storms are a complex process influenced by the interplay of the earth-atmosphere system and are created mainly by high wind speed, dry air conditions, bare soil, and other factors [12], [13], [14].

Three categories apply to the lower troposphere's dust storms according to reduced visibility and are often used to describe the severity of dust storms (Table 1) [15].

Table 1: Categorization of dust storms

Dust storm type	Horizontal visibility (vv) (km)	Wind speed (ff) (m/s)
Severe	$0 \le vv \le 0.2$	$8 < ff \le 18$
Moderate	$0.2 < vv \le 0.5$	$8 < ff \le 12$
Light	$0.5 < vv < 1$	$8 < ff \le 10$
Non-dusty	$vv = 10$	$ff \ge 0$

The aim of the research is to examine the trajectory of a severe dust storm in Iraq on May 16, 2022, and determine the local and regional dust exporting areas. This is necessary, due to the frequency of dust storms occurrence in Iraq in recent years, so that the relevant government agencies can address them to mitigate their damage to the climate, environment, and public health.

Analysis of statistical data, identification of dust source areas and entrance points, and further identification of this phenomenon are necessary to understand and mitigate its negative impacts [16].

2. Materials and Methods

This study presents a spatial and temporal analysis of a severe dust storm in Iraq on May 16, 2022, regarding synoptic weather conditions. The analysis includes the following steps: First, using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model to determine the backward trajectory path of the dust storm by identifying six different locations throughout Iraq as the path's endpoints. Then, the results obtained from the HYSPLIT model were compared with Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images and with Spinning Enhanced Visible and Infrared Image (SEVIRI) radiometer from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) products. Secondly, a comprehensive analysis of weather conditions, such as surface pressure, wind speed, and temperature, at different geopotential heights uses the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis model. Finally, after identifying the dust storm sources, Unsupervised Iterative Self-Organizing Way of Performing Clustering (ISODATA) classification method for multispectral Landsat 8 satellite images by Environment for Visualizing Images (ENVI) was used to determine the approximate area of these sources.

2.1. Study Area

Iraq is located in southwest Asia between two longitudes (38.42–48.45) ˚E and latitudes (29.5–37.22) ˚N in the so-called "dust belt," which spans from the west of North Africa to China via the Middle East, South Asia, and Central Asia [17]. Iraq's total area is 438,317 km^2 [18]; it is bordered to the south by Kuwait and Saudi Arabia, Turkey to the north, Syria and Jordan to the west, and Iran to the east [19]. Four physiographic areas may be identified on the territory of Iraq according to the nature of land terrain into four regions [20]: the Mountain Region in the northeast, the Plateau and Hills Regions in the north among the Euphrates and Tigris rivers, the alluvial plains in the central and southeastern parts, and the Jazeera and Western Plateau in the west and south. It is an immense desert region covering approximately 168,000 km^2, nearly two-fifths of Iraq's area (Figure 1). The western desert, a stretch of the Syrian Desert, reaches heights of about 490 m. Iraq's weather is characterized by sand-blowing, wind-raised dust, and degraded soil [21], [22]. The climate is mainly continental, subtropical, and semi-arid [23].

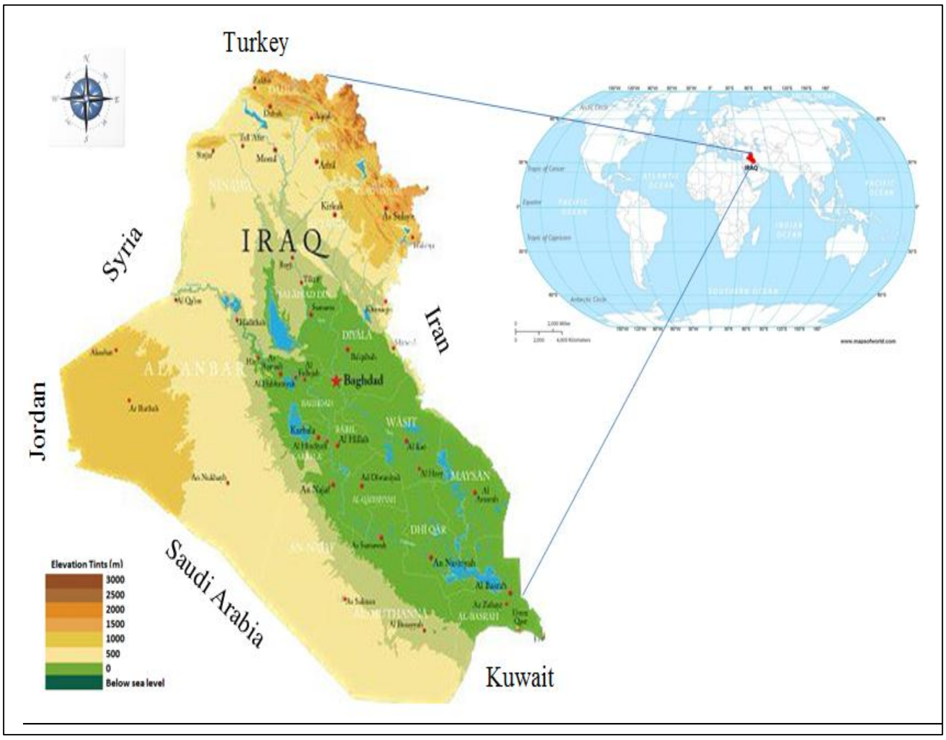


Figure 1: Location of Iraq in the world map

2.2. Satellite products and models

Satellite imaging of the earth's surface and atmosphere is essential for monitoring air quality and pollution because of its comprehensive spatial and temporal monitoring of the earth's surface and atmosphere [24].

MODIS, an essential sensor on the Aqua (EOS PM) and Terra (EOS AM) satellites have been launched by NASA [25]. MODIS produces observations with spatial resolutions of 0.25, 0.5, and 1 km using 36 spectral band wavelengths of 0.41–14.4 µm [26]. It plays an essential role in monitoring dust occurrences on Earth by identifying dust storms using optical satellite pictures based on particle radiation and scattering properties [27].

METEOSAT is the currently operational satellite in the Meteosat Second Generation series [28]. The main device on board Meteosat Second Generation (MSG) satellites is the **SEVIRI** radiometer [29]. **EUMETSAT** affords extensive display information about climate from earth observation, environment, and weather [30]. EUMETSAT operated (MSG) satellite records over Africa and Europe from a geostationary track about 36,000 km above the equator [31]. MSG observes all steps every 15 min. Brightness temperature readings from SEVIRI at 8.7, 10.8, and 12 µm, existing on a 0.05◦ grid every 15 min, are processed to produce false-color images that make it simple to recognize dust clouds [28].

HYSPLIT model uses geographically and temporally gridded meteorological data to simulate air parcel movement caused by wind advection [32], [33], [34]. It is considered one of the most often used models for the distribution and transport of atmospheric pollutants in large-scale research, and it was established and developed by the National Oceanic and Atmospheric Air Lab of the United States [35]. It was employed to locate the dust's source and follow the dust particles' course [36]. Backward trajectory models were carried out to determine the starting location of the dust storm and the direction of its movement over the Middle East and Iraq [37].

NCEP/NCAR Reanalysis Model, which provides incredibly detailed and precise data on the state of the atmosphere and its changes, is widely used in atmospheric and climate research and weather forecasting [38]. It is a model used in atmospheric reanalysis to examine meteorological and climatic data [39]. These models generate sequential time records of atmospheric variables over lengthy periods using prior weather data, including temperature, pressure, wind speed, and more [40]. Data from NCEP/NCAR are accessible on the NOAA website [41].

Landsat 8 satellite involves two scientific instruments: an operational land imager (OLI) and a thermal Infrared Sensor (TIRS)" [42]. These instruments give periodic coverage of the whole earth with 30 m spatial resolutions (visible, NIR, and SWIR) [43]. Radiometric performance and spectral coverage are intended to identify and describe the terrestrial cover change [44].

3. Results and discussions

3.1 . Study Dust Storm (May 16, 2022)

May is characterized by a rise in the frequency of dust storms [45], [46]. This month has seen less humidity and precipitation, an increase in temperatures, and, therefore, an increase in dust frequency [46]. On May 16, 2022, a dust storm spread over a significant portion of Iraq. Due to its severity, it was one of Iraq's most intense storm incidents in 2022. The severe dust storm continued from its entry into the borders of Iraq until it receded for about 30 h, starting from 12:00-UTC on May 15, 2022, to 17:00-UTC on May 16, 2022. The storm affected several cities throughout Iraq. The massive fast-moving storm led to a decrease in visibility to close to zero with wind speeds of 23.7 m/s, according to data from the Iraqi Metrological Organization and Seismology. The authorities have been forced to order hundreds of thousands of students and government employees to stay at home because of the awful weather and worsening respiratory issues [47]. Additionally, all outward and incoming flights were canceled at the airports in Baghdad, Najaf, and Sulaymaniyah [47]. Figure 2 displays the Aqua MODIS images of the dust storm in Iraq that were obtained on May 16, 2022.

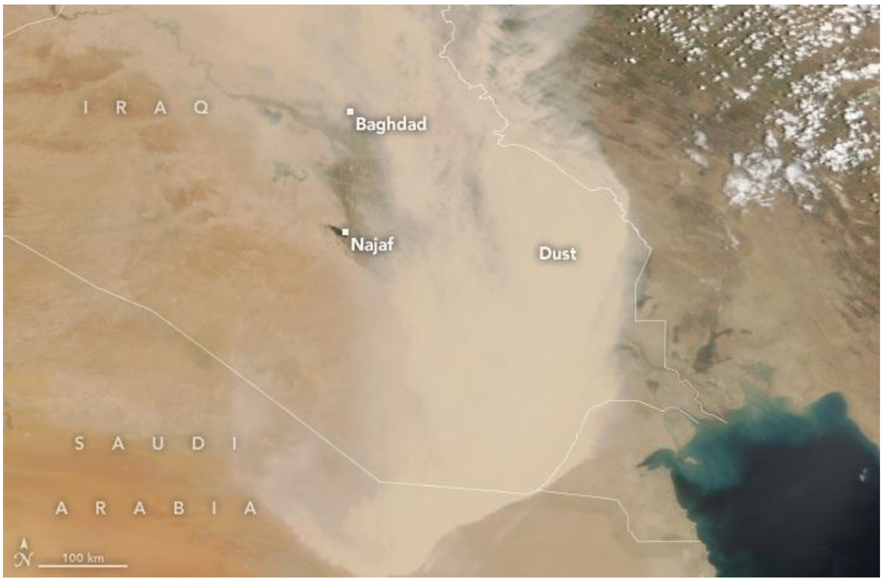
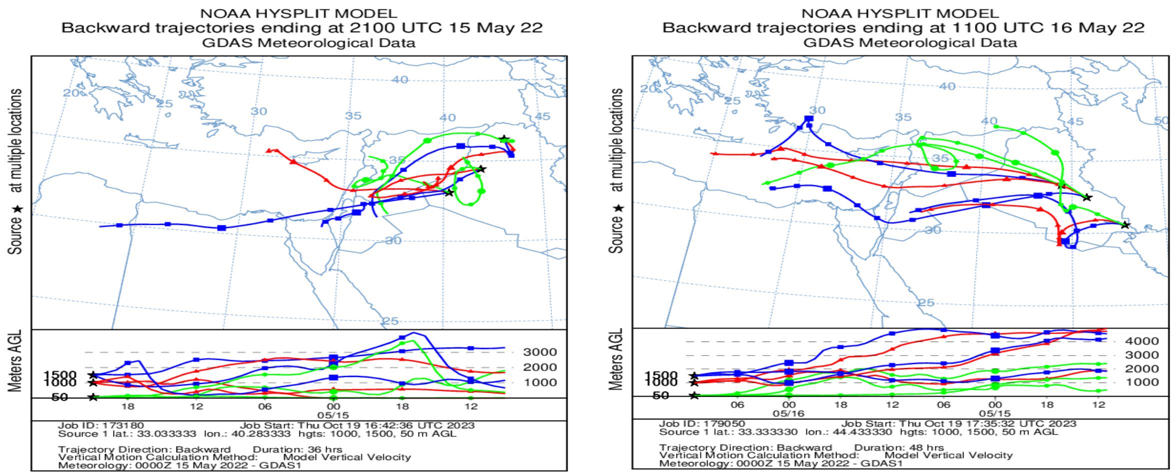


Figure 2: Natural-color images captured by NASA Earth Observatory (Aqua MODIS) on May 16, 2022 [48]

3.2. HYSPLIT Trajectory Simulation

The HYSPLIT model is configured to determine the backward trajectories, Figure (3). The calculation of the route is carried out by the location time integration of the air expulsion through three-dimensional winds in two patterns: the first pattern ends at 21:00-UTC on May 15, 2022, with the duration of each track being 36 h. for two areas in the Anbar Governorate (Rutba and Rawah) and Mosul in the Nineveh Governorate, Figure 3a. The second pattern in Figure 3b ends at 11:00-UTC on May 16, 2022, with the duration of each track being 48 h for the governorates (Baghdad, Wasit, and Basra). The two pattern trajectories were selected to analyze the 50, 1000, and 1500 m above-ground levels.



(a) **(b)**

Figure 3: HYSPIT backward trajectories of a dust storm. (a) at 21:00-UTC May 15, 2022, (b) at 11:00-UTC May 16, 2022

The results of the HYSPLIT model for the first pattern are displayed in Figure 3a. For the three altitudes of 50, 1000, and 1500 m on May 15, 2022, the likely source of the dust in the study region from territorial states is the shared border region between Syria (Rif-Dimasshq) and Jordan (north of Al-Ruwaished). The second pattern is shown in Figure 3b. For the three altitudes of 50, 1000, and 1500 m on May 16, 2022, the likely source of the dust in the study region was local, that is, the northwestern regions of Iraq, specifically north of Anbar and south of Nineveh, in addition to being the first source of a dust storm.
To corroborate the results obtained from HYSPLIT, the study used MODIS satellite images and false colors from the SEVIRI instrument onboard the Meteosat Second Generation spacecraft used in this study. The temporal and spatial coverage computed by HYSPLIT was highly consistent with the MODIS images. MODIS visuals of the study region for case studies are shown in Figure 4. Figure 4a displays the dust on May 15, 2022, in Syria and Jordan at 6:00-UTC. Figure 4b shows the dust storm on May 16, 2022, covering large regions of Iraq. Finally, it went to Kuwait and Saudi Arabia in the south and Iran in the east; thus, MODIS observations established the output of the HYSPLIT model.

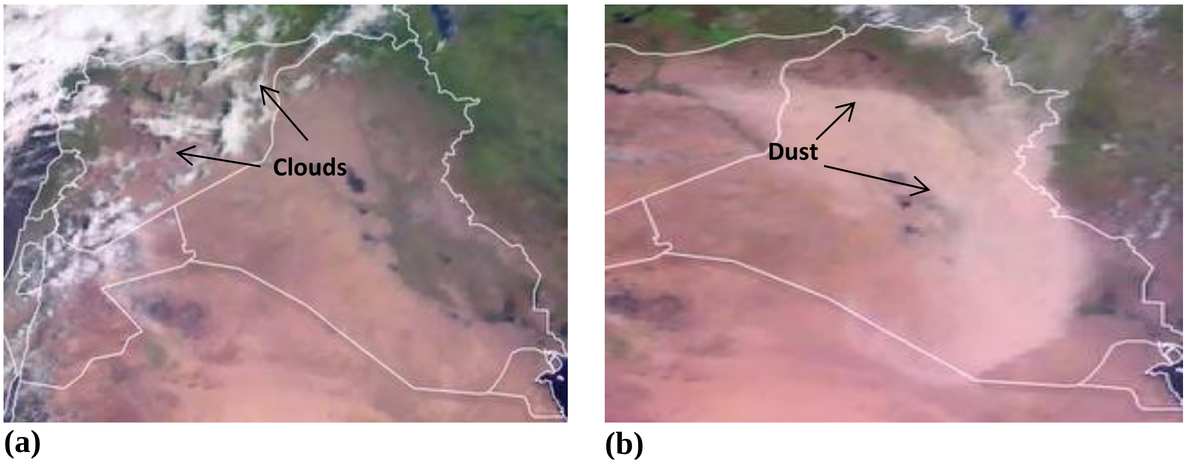


Figure 4: MODIS images for case studies, (a) at 06:00-UTC May 15, 2022, (b) at 08:00-UTC May 16, 2022 [49].

3.3 EUMETSAT Images Analysis

EUMETSAT suggests using specific RGB images for dust observation. Dust RGB Images is an RGB product built using SEVIRI's infrared channel data, and it has pink dusty pixels. It is intended to track the dust storms' progression during the day and night. SEVIRI images are used for monitoring dust storm events. Execution of RGB images urged by EUMETSAT for observing dust with MSG for a dust storm in the Middle East on May 15–16 is shown in Figure 5. According to the EUMETSAT observations and the HYSPLIT simulation, temporal and spatial coverage were very in agreement.

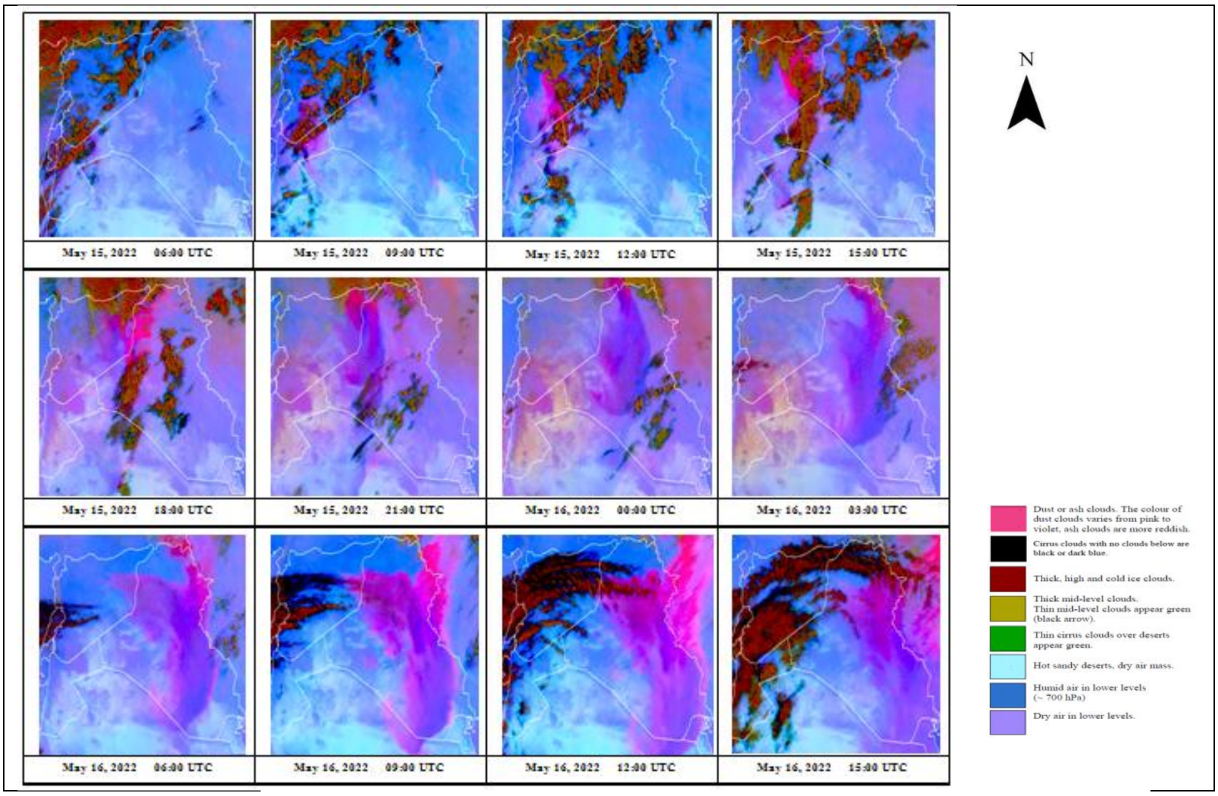


Figure 5: Dust RGB images for case study every 3 h during May (15-16), 2022 [49]

3.4 Meteorological Analysis

Figure 6 shows the synoptic maps on May 15, 2022, before a dust storm in the Middle East. Synoptic maps of the geopotential height of 850 and 500 mb, surface pressure, temperature, wind velocity, and direction were created and analyzed using NCEP/NCAR. The surface pressure Figure 6a indicates that the low-pressure system (78000 Pa) stretched east of Turkey to Iran eastward of Iraq. It is also seen that a high-pressure system (102000 Pa) was formed over the Mediterranean Sea. Differences in the air pressure system cause the wind to blow from the high-pressure area (Mediterranean Sea) to the low-pressure area (Iran), passing through Syria, Jordan, and Iraq.

Other factors, such as geopotential height maps, can influence wind patterns, Figures 6b and 6c. According to the 850 mb geopotential height level map, there are low levels over Europe and Pakistan (1440 m), and the wind flows clockwise, Figure 6b, there is a Height level over north Africa (1590 m), and the wind flows counterclockwise. According to the 500 mb geopotential height level map, there are low levels over Europe (5600 m), and the wind flows clockwise, Figure 6e, there is a Height level over Saudi Arabia (5950 m), and the wind flows counterclockwise.

The convergence of geopotential height lines indicates the approaching of atmospheric pressure levels. This means that areas with greater convergence (Mediterranean Sea, Jordan, and Syria) are inclined to sudden and substantial weather changes, which leads to the existence of turbulence in air movement and causes cyclonic movements that result in wind with an orientation of west to east toward western areas of Iraq with a surface wind speed of 6–8 m/s, Figure 6f and surface tempura about 297 k, Figure 6h. This led to lift dust from desert areas (Syrian Desert) and generating a dust storm. Over the Middle East, wind speeds near-surface greater than 7 m/s are required for dust emissions to occur [50], [51]. The amounts of shear stress and surface roughness impact how quickly sand and dust particles travel, and this effect tends to grow as wind speed increases. Long-distance dust transport is frequently caused by these particles being moved along with the global atmospheric flow patterns. The wind map at 500 mb geopotential height in Figure 6e shows high-speed values up to 36 m/s with temperature 258 k as shown in Figure 6g and the wind map at 850 mb geopotential height in Figure 6d shows high-speed values up to 10 m/s over the shared border region between both Syria (Rif-Dimasshq) and Jordan (north of Al-Ruwaished desert) which leads to the development of a dust storm at 6:00-UTC on May 15, 2022, which are believed to be the primary sources of dust storms in the area.

Dust sustained to be emitted during the day and covered the central parts of Syria. It tacks its direction toward the northeast of Syria and reaches the western part of Iraq (Anbar Province) at 18:00-UTC. Synoptic maps on May 15, 2022, at 18:00-UTC when the dust storm entered western Iraq are illustrated in Figure 7.

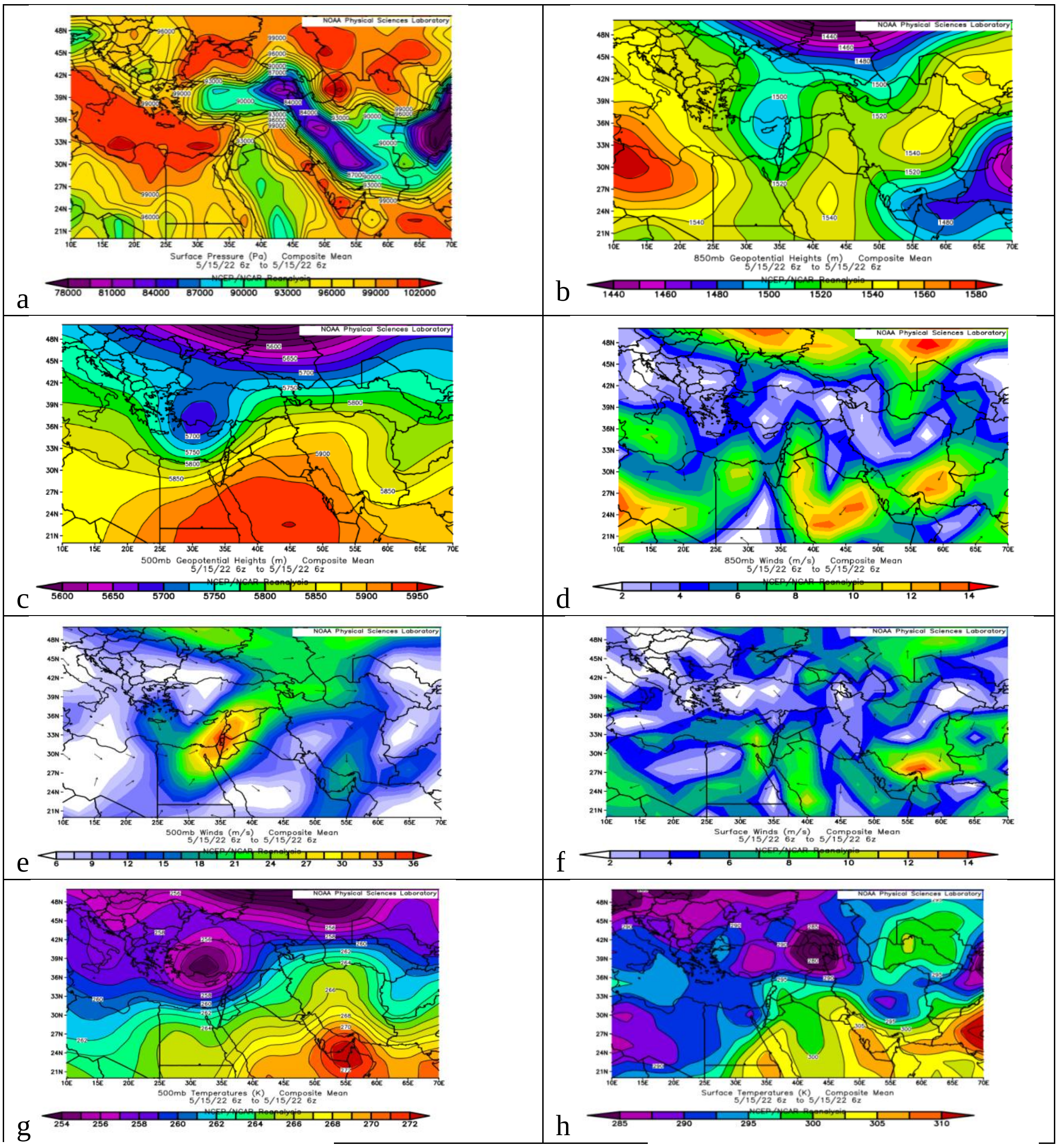


Figure 6: Synoptic maps for meteorological parameters on May 15, 2022 (06:00-UTC). (a) Surface pressure, (b) 850 mb geopotential height, (c) 500 mb geopotential height, (d) 850 mb winds, (e) 500 mb winds, (f) Surface winds, (g) 500 mb temperature, (h) Surface temperature.

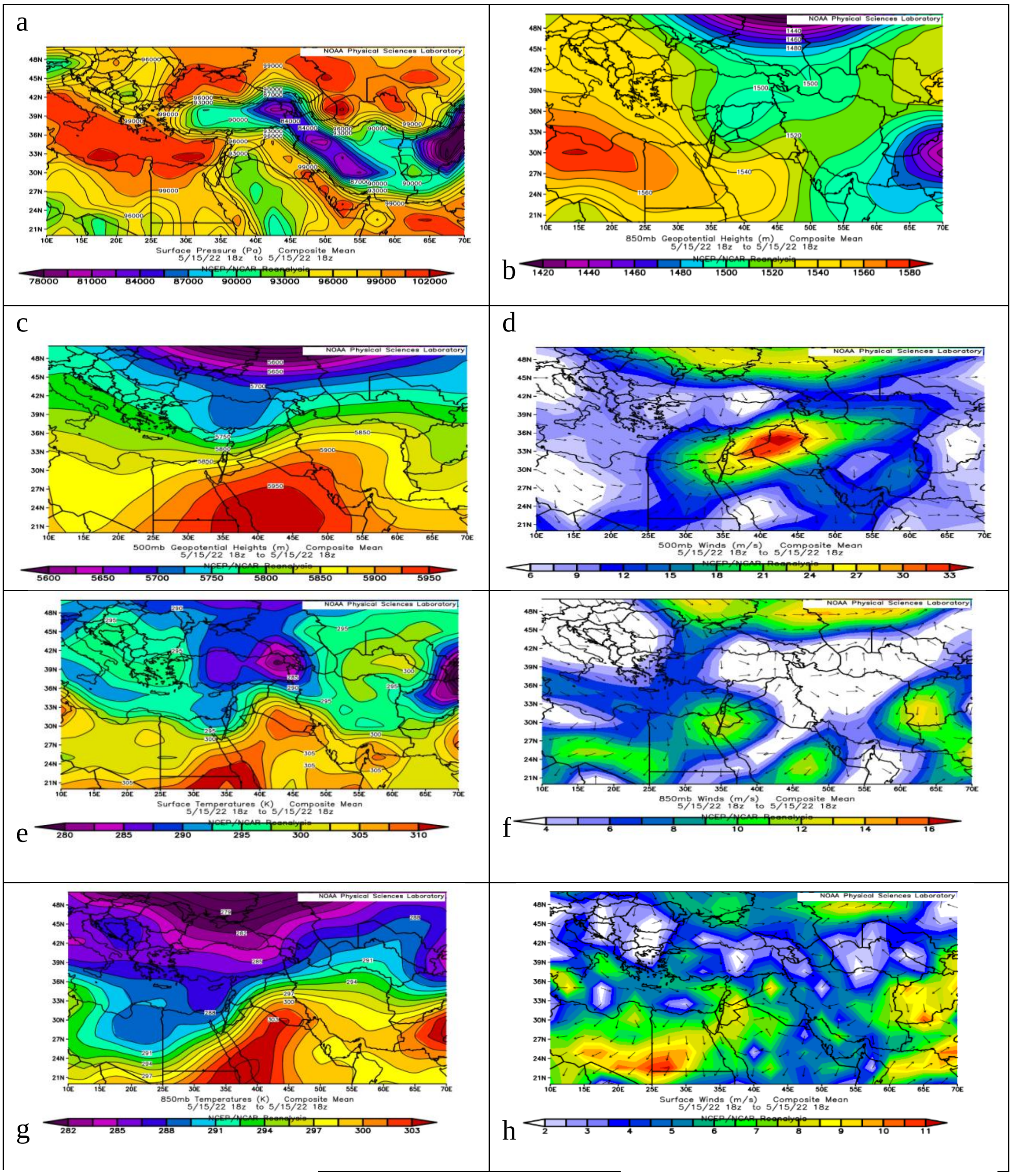


Figure 7: Synoptic maps for meteorological parameters on May 15, 2022 (18:00-UTC). (a) Surface pressure, (b) 850 mb geopotential height, (c) 500 mb geopotential height, (d) 500 mb winds, (e) Surface temperature, (f) 850 mb winds, (g) 850 mb temperature, (h) Surface winds

The surface pressure in Figure 7a and the geopotential height in Figures 7b and 7c indicate that the region was in the same meteorological conditions as described earlier at the beginning of the dust storm. As seen in Figures 7d and 7f the air masses loaded with dust moved toward the western parts of Iraq at speeds of 30 m/s at 5600 m and 9 m/s at 1520 m with temperature 291 k, Figure 7g. When air masses enter Iraq's northwestern regions, specifically north of Anbar and south of Nineveh, where they have a speed of approximately 9 m/s as seen in Figure 7h, and a temperature of about 295 K, Figure 7e, these values are identical to those recorded by the meteorological station (Al-Rutba Meteorology Station) in Anbar Governorate. The air mass encountered southwesterly warm winds with 9 m/s surface speed and temperature of about 308 K, Figures 7h and e, respectively. The wind speed and the rise in surface temperature contributed to the continuation of the dust storm and the increase in the amount of suspended dust particles, which caused the cyclonic movements of dust occurrence and its transfer to upper levels, which led to the transportation of dust particles over longer distances. North of Anbar province and south of Nineveh is conceded as the second source, in addition to the primary source of dust storms accrued in Iraq. By horizontal flows and their movements, this dust storm on the next day (May 16, 2022) at 12:00-UTC extended to cover most of western and central Iraq and then propagated toward the southeast, causing a massive dust storm over Iraq.

Synoptic maps for May 16, 2022, at 12:00-UTC, are illustrated in Figure 8. The surface pressure in Figure 8a and the geopotential height in Figures 8b and 8c indicate that the region is still under the meteorological conditions described earlier. After the increase in storm intensity within the Iraq borders, the air masses loaded with dust by northwest winds moved to the eastern and eastern parts of Iraq at speed of 27 m/s at 5600 m and 14 m/s at 1520 m (Figures 8d and 8f), respectively. The temperature decreased at the surface and 1500 m (Figures 8e and 8g), respectively, and the surface speed decreased compared to the previous day to approximately 6 m/s (Figure 8h), causing suspended dust in the air for a long time. The dust storm persisted for approximately three days, from the time it entered the Iraqi borders until it subsided. During this period, the storm caused a significant reduction in visibility and increased the amount of suspended particulate matter in the air, leading to transportation disruptions and other activities in the affected areas. The storm duration is consistent with the typical duration of dust storms, which can last for several hours to a few days, depending on the size and intensity of the storm and the local weather conditions.

According to data from the Iraqi Metrological Organization and Seismology, the dust storm reached Kirkuk Governorate, north of Baghdad, on May 15, 2022, at 22:00-UTC, where the visibility range decreased from 10 km to 500 m, so that the visibility range continued to decrease until it reached less than 100 m in the following 30 h, where the visibility range alternated between 100 and 900 m and the wind speed ranged from 1 to 6 m/s. The visibility range returned to 10 km on May 17, 2022, at 8:00-UTC.

The dust storm reached Baghdad on 15/5/2022 at 23:00-UTC, where the visibility range decreased from 10 km to less than 100 m so that the visibility range continued to decrease until it reached less than 100 m in the following 33 h, where the visibility range alternated between 100 and 900 m, where wind speed ranged from 1to 4 m/s, then the visibility range returned to rise to 10 km on 17/5/2022 at 9:00-UTC.

The dust storm reached Basra on 16/5/2022 at 7:00-UTC, where the visibility range decreased from 10 km to 3 km so that the visibility range continued to decrease until it reached less than 100 m in the following 23 h, where the visibility range alternated between 0.1 and 1 km, where wind speed ranged of 3-6 m/s, then the visibility range returned to rise to 5 km on 18/5/2022 at 6:00-UTC.

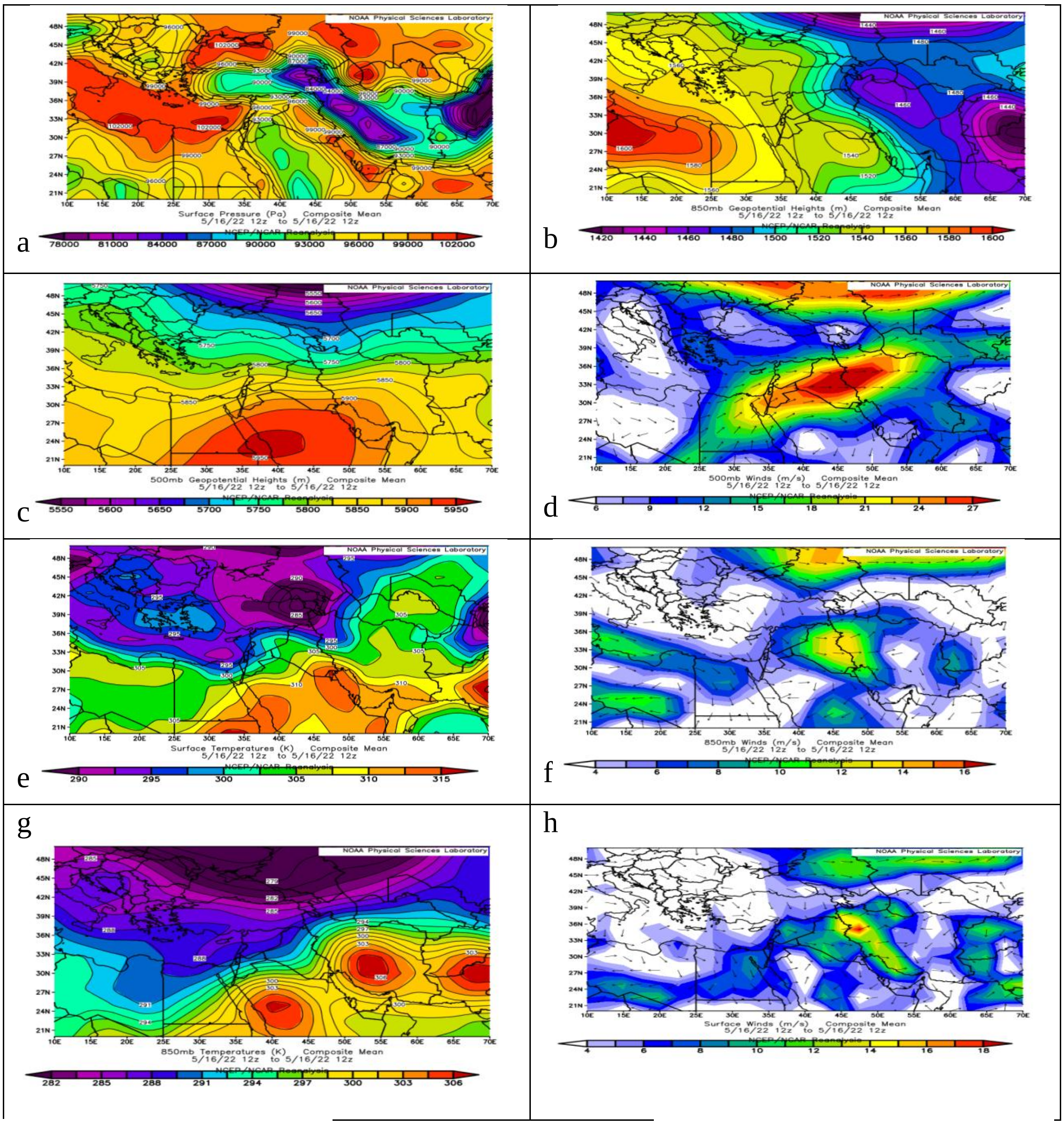
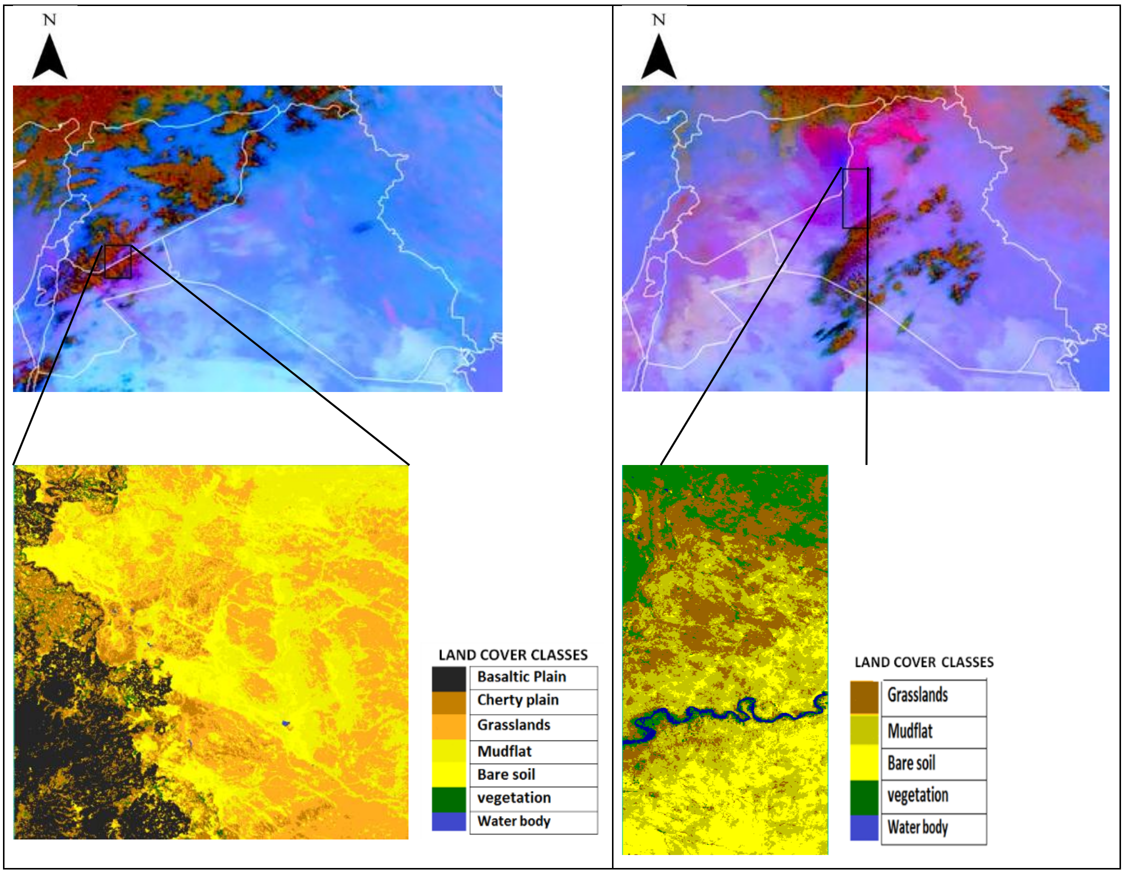


Figure 8: Synoptic maps for meteorological parameters on May 16, 2022 (12:00-UTC). (a) Surface pressure, (b) 850 mb geopotential height, (c) 500 mb geopotential height, (d) 500 mb winds, (e) Surface temperature, (f) 500 mb winds, (g) 850 mb temperature, (h) Surface winds

3.5 Dust storm source areas determination

The northwestern wind from the Syria and Jordan deserts through the northwestern Iraq desert carried the dust to Iraq's central and southern regions. The area of these two dust storm sources can be determined to contribute to supporting the concerned authorities with knowledge of dust-exploring regions and to plan for treatment and mitigation of dust storms and their damages by estimating the treatment methods and costs based on the calculated dust-exporting areas. The Unsupervised Iterative Self-Organizing Way of Performing Clustering (ISODATA) classification method for multispectral LANDSAT 8 satellite images by Environment for Visualizing Images (ENVI) was used. The two dust storm sources are illustrated in Figure 9.



(a) (b)

Figure 9: the two sources of dust storm accrued in Iraq on May 16, 2022 ;(a) regional sources,(b) local sources

Primary dust storm sources and their areas are identified. The first source, Figure 9a, is the shared border region between Syria (Rif-Dimasshq) and Jordan (north of Al-Ruwaished), with an area of about 775 km^2. The second source, Figure 9b, is for the northwestern regions of Iraq, specifically north of Anbar and south of Nineveh, with an area of about 905 km^2.

4. Conclusions

1. The HYSPLIT model used to track the movement of dust shows excellent efficiency and is a helpful tool for comprehending the processes involved in the emission, transportation, deposition, and geographic dispersion of dust. The results of the HYSPLIT model agree with the results of the satellite products.
2. Examining the path of incoming winds to the region that causes dust storms shows that a part of the incoming winds, after passing through the active dust sources in the west of Iraq, is strengthened, causing an increase in the concentration of storms and decreasing the horizontal visibility in the study areas.
3. Identifying the sources of dust storms is essential due to the frequency of their occurrence in Iraq. This is necessary so that the relevant government agencies can address them to mitigate their damage to the climate, environment, and public health.
4. Primary dust storm sources and their areas are identified. The first source is from the shared border region between Syria (Rif-Dimasshq) and Jordan (north of Al-Ruwaished), with an area of about 775 km^2. The second is from the northwestern regions of Iraq, specifically north of Anbar and south of Nineveh, with an area of about 905 km^2.
5. Seasonal climate strongly influence the occurrence and distribution of dust storms. Due to drought for more than two decades, harsh environmental conditions, formations sensitive

to erosion, and vast masses of quicksand in the study area and surrounding areas, especially in Syria and Jordan, have predisposed the conditions to intensify this situation.

6. Serious measures should be taken regarding planning to reduce the desertification process, as well as the implementation of regional and international plans.

Acknowledgments

We greatly appreciate the efforts of the following agencies: the Iraqi Meteorological Organization and Seismology, the Iraqi Ministry of Science and Technology, the National Aeronautics and Space Administration (NASA), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), and the National Centers for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) for offering mapping and data of meteorological parameters.

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